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A Study on Crop Growth Environment Control System

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Abstract

The concept of "Plant factory" could realize the multiple targets of high yield, high quality, high efficiency and security. It had become the trend of agricultural development. It solved the growing contradiction between people's increasing demand for green, organic food and the diminishing agricultural arable area in China. According to the research on the key technologies of plant factory, a small simulated environment for crop growth (i.e., a growth cabinet) was designed. The growth cabinet used the light-emitting diode (LED) light source as crop growth light and simulated ecological environment artificially based on the requirement of crop growth and development. The crop can obtain suitable environmental conditions for growth and development in anti-season and non-suitable environmental conditions by using the sensor and embedded technology. The results of experiments showed that the crop growth cabinet's structure design was reasonable and had the advantages such as reliable performance, low-carbon, intelligence and security.

Keywords: *crop, environment control, LED light source, embedded system*

1. Introduction

In recent years, with the development of agricultural science, system science and computer technology, the study on crop growth environment simulation system has gradually become a new area of research. The crop growth environment simulation system is an automated or semi-automated control system in greenhouse or other enclosed environment by simulating the natural environment of crop growth with environment control technologies. Greenhouse, plant incubator, crop growth cabinet and plant factory are the macro reflect of crop growth environment simulation system. Plant factory was recognized as the world's most advanced stage of development of agricultural facilities, and was considered as the most effective techniques in the future to solve the population, resources and environmental issues[1].

Temperature, humidity, light, carbon dioxide (CO_2) concentration and nutrient are the main environmental regulatory factors affecting crop growth. The computer control system of the simulated environment for crop growth controls the environmental heater, refrigerator, fan, water pump, nutrient solution heating refrigerating unit and humidifier actuators through issuing instructions in real time. Until now, the control system for the crop-growth simulated environment, especially for the greenhouse, has achieved rapid development. Many kinds of technology and equipment have been used in the control of the environmental parameters of greenhouse. Kameoka *et al.*, [2] used wireless sensor technology in the detection of crop factory environmental parameters, so as to realize automatic control of environment parameters. Park *et al.*, [3] studied the best

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environment parameters for moss growth in the commercial crop factory, so as to realize the efficient production of moss and gain the maximum output. The autonomic regulation of the simulated environment has become the development trend of greenhouse [4-7].

Whether crop growth environment simulation system could achieve the targets of high yield, high quality and high efficiency, one of the core technologies is environmental control technology. Dynamic mathematical model, optimal control of target parameters, powerful control and optimization algorithms of precise crop growth environment are the key of obtaining good performance of environmental control systems. Bennis et al[8] applied the robust control in the control of temperature and humidity in greenhouse, gained process linear control model by the off-line parameter identification technique, and used H_2 robust control on this basis. Blasco et al[9] used a model based predictive control, built a greenhouse environmental model, used the method of predictive control scroll optimization to optimize water and energy consumption targets and gained the controlled quantity. Hahn[10] proposed a fuzzy controller, which was used to control the greenhouse environment and climate, thereby reducing the cracking in tomato growing process. Qu et al[11] used the Radial Basis Function-Proportion Integration Differentiation (RBF-PID) control strategy combining RBF neural network and conventional PID, according to the problems of large lag, large inertia in the greenhouse temperature control system, to adaptively adjust temperature PID controller parameters, and achieved the high-quality control of greenhouse temperature system. Wang et al[12] proposed an idea and method of solar greenhouse for temperature, humidity fuzzy control, and used decoupling parameters for temperature decoupling.

With the innovation of photoelectric technology, LED for its advantages of good spectrum performance, could satisfy spectral range of light synthesis and morphogenesis in crop growth. The advantages of highly effective utilization rate of light energy, individual control of different light quality and luminous intensity, resistance to impact, long life and no environmental pollution made LED gradually become the preferred light source for crop growth environment simulation system. LED has become the new light source for test-tube seedlings growth and morphogenesis, and was widely used in plant factories and greenhouses of vegetable cultivation and fruit production in the world. Ernesto et al[13, 14] designed an intelligent lighting system for the study of the fluorescent effect of tomato under different frequencies of lighting conditions. Jai et al[15] studied the influence of crop germination and growth under different proportions of red and blue light sources. Olle[16] studied the effects of crop growth process and quality of various greenhouse crops under different parameters of LED.

In China, research on LED light source in the application of crop growth has also made some corresponding outcomes[17-19]. LED combination light source suitable for higher crop cultivation had been studied by the Institute of China Aerospace Medical Engineering[20], as early as 1998. Scientific research institutions such as Chinese Academy of Agricultural Sciences and Nan Jing Agricultural University had already begun research the related field of LED agriculture application.

At present, most of the application research scope about the LED light source in crop growth was only focus on a few crops, and only one or two kinds of colors of the used LED light sources were produced, which cannot fully meet the requirement characters of light in the process of crop growth. Therefore it is necessary to explore the promotion mechanism of LED light source according to the crops growth mechanism at first, and then build a LED light source parameters system in line with the crop growth based on that, and finally design a LED light source suitable for crop growth. In our research, LED was used as the lighting source for crop growth. Combining with embedded technology and sensor technology, we designed a crop growth system, i.e., an intelligent crop growth cabinet, to simulate the natural environment. The cabinet could regulate the temperature, humidity, light intensity, and carbon dioxide concentration, and it achieved the increase of crops yield in a small scale. The proposed design had laid the foundation and provided technical support of large-scale promotion in the future.

2. Analysis of Environmental Factors on Growth of Crops

2.1. Effect of Temperature on Crop Growth

There are two main aspects that temperature affects the growth of the crops. Firstly, it could affect the metabolic process of photosynthesis, respiration, transpiration, as well as the metabolism processes of organic synthesis and transport. Secondly, it could also directly affect the soil temperature, air temperature, and indirectly it affects the absorption and transporting of water and fertilizer.

In the process of crop growth, photosynthesis, respiration and other metabolic activities need a chemical substance -- enzyme, whose activity varied with the temperature changing. Crop growth needs an appropriate temperature range. In the optimal temperature range of crop growth, crop could grow fastest and the most accumulation of organic matter was produced.

At the same time, the content of chlorophyll in crops would also change along with the change of the temperature to a certain extent, enzymes involved in the vast majority of synthesis of chlorophyll, low temperature affects the activity of enzymes and the synthesis of chlorophyll, accelerates chlorophyll degradation speed[21].

2.2. Effect of Humidity on Crop Growth

No crops can grow without water. Water is the power of crop cell expansion growth. The process of cell expansion growth needs plenty of moisture to make cells produce the expansion pressure. If the cells lack of water, cell expansion growth is stunted, then the crops would be very short. On the other hand, the water is the primary condition of various physiological activities of crops. Crop growth needs to accumulate a certain amount of organic matter as raw materials to build the cell wall and protoplasm, these materials are the main products of photosynthesis, and water is the necessary condition for the smooth progress of photosynthesis, when lacking of water, the photosynthetic efficiency of crops is reduced.

In addition, the humidity is the main cause of crop diseases. In greenhouse, high humidity would cause the fungal diseases, crop leaf necrosis, crop leaf would be weak and thinner, and crop emergence rate is decreased. On the contrary, if the humidity is too low, the saturated vapor pressure difference (VPD) will be too high; the growth of crops is also unfavorable[22].

2.3. Effect of Light on Crop Growth

There are direct and indirect effects of light on the crop growth: the direct one refers to the light effect on crop morphology formation, in terms of crop growth process itself, it does not need light. As long as there is enough nutrition, crops could grow in the dark. But if crop is in the dark, the form was abnormal. The indirect effect mainly refers to the photosynthesis, which absorbs the CO_2 in the air to synthesize organic material, which is the material basis of crop growth. Crop leaves absorb 1 mol of CO_2 would take about 468.6 kJ (kilojoules) light, so the light affects the crop growth through photosynthesis.

The light environment is divided into three parts: light intensity, light quality and light cycle.

In the range of visible light, the effect of light on crop growth and development are not the same, as shown in **Table 1**. The efficient wavelength of photosynthesis is between 400~700nm, where 400~520nm (blue light) and 610~720nm (red light) have the greatest contribution on photosynthesis. Studies show that red light plays an important role in the normal development of the photosynthetic apparatus, red light could increase leaf starch accumulation by inhibiting photosynthetic product; the blue light could regulate physiological process of chlorophyll formation, chloroplast development, stoma opening and rhythm of Photosynthesis and so on. Appropriate luminous flux ratio of red (610 ~ 720 nm) and blue (400 ~ 520 nm), *i.e.*, R/B, could ensure cultivate crops with healthy morphology[23, 24].

Table 1. Effect of Spectral Range on Crop Physiology

Wavelength/nm	Promoting effect
280 ~ 315nm	Effects on the morphological and physiological process is small
315 ~ 400nm	Chlorophyll absorption is less, influence photoperiod effect, prevent stem elongation
400 ~ 520nm(blue)	Chlorophyll and carotenoid absorption ratio in the wavelength is largest, impact on photosynthesis is biggest
520 ~ 610nm(green)	Absorption rate of pigment in the wavelength is not high
610 ~ 720nm(red)	Chlorophyll absorption rate is very low, have significant effects on photosynthesis and light cycle
720 ~ 1000nm	Absorption rate is low, stimulates cell elongation, affects seed germination and blossom

2.4. Effect of CO_2 on Crop Growth

CO_2 is an important raw material of photosynthesis, and it is also a product of respiration, the change of CO_2 concentration would affect the physiological processes of crop growth. When the CO_2 concentration increases, on the one hand it directly increases the photosynthesis substrate, and increases the CO_2 partial pressure in chloroplast, improves the CO_2 competitiveness for Rubisco enzyme, influences the direction and activity of Rubisco, increased the carboxylation efficiency of Rubisco, decreases the oxidation efficiency and increased the net photosynthetic rate. On the other hand, because of the increased CO_2 concentration, it would change the system structure of crop photosynthesis, improve the activity of optical system and increase the rate of photosynthesis. CO_2 concentration has a promoting effect on crop photosynthesis, but when the CO_2 concentration exceeds the saturation point, even it further increases, the photosynthetic intensity would not increase, instead it plays a role of inhibition for photosynthesis[25].

2.5. Effect of Nutrient on Crop Growth

Nutrition is one of the primary indispensable factors in crop growth, different crops and different stages of crop life cycle have different needs for nutrients. Too much nutrient, crops would appear poisoning phenomenon; On the contrary, crop would be nutrient malnutrition. At the same time, crops are selective on the absorption of nutrients, so we should understand clearly the kinds and uptake of mineral elements in the process of crop growth. Once lacking of certain nutrients in crop growth process, it would cause the obstacle in crops growth, and display in the form of crop.

2.6. Study of Microclimate Models on Crop Growth

Crop demand for environmental factors could be summarized as: in line with the rule of the growth cycle of crop growth, every environmental factor influences and is associated with each other, forming a comprehensive dynamic environment. In the process of crops growth and development, they need certain conditions of illumination, humidity and temperature, if environmental conditions are not satisfied, crops would stop growing, occur diseases, even become decay and death. To make crops get the best optimum growth condition, we should comprehensively study the effects of various environmental factors on the crops growth and development and timely make reasonable regulation.

The greenhouse simulation system includes two parts: greenhouse environment simulation and crop growth simulation. This paper focuses on the simulation of crop growth environment, and establishes a crop physiology environment model which could feedback simultaneously temperature, illumination, CO_2, other environmental factors and part of the physiological and ecological indicators at the same time, to predict the optimal environmental conditions of crop physiological information target at the next moment, so as to determine the executing agency action. The structure diagram is shown in Figure 1.

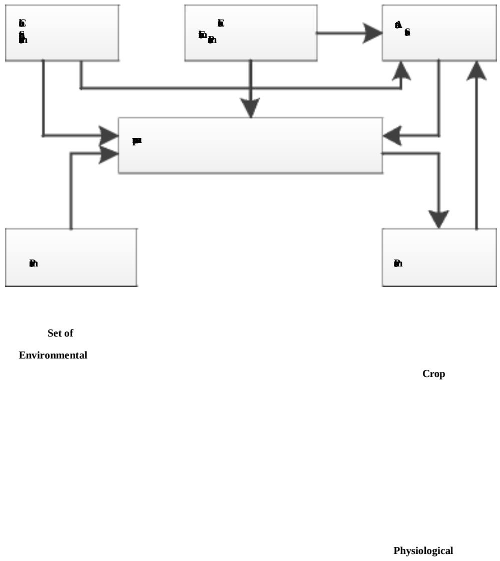
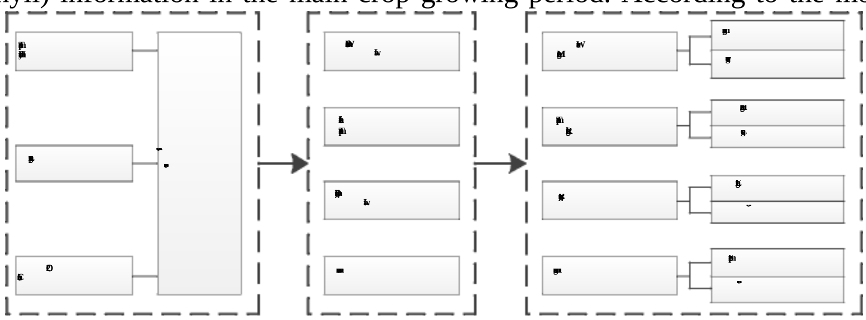


Figure 1. Diagram of Crop Growth Environment Model

The topic used greenhouse crops as the main research object, based on science theory, system analysis of the research results at home and abroad, adopted scientific test method, chose the typical crop varieties, used LED as artificial light source to cultivate crops, focused on temperature, light, water, nutrition and other environmental factors on crop growth and development, used advanced sensor technology and modern testing technology, obtained the basic factors of temperature, moisture, illumination and so on in greenhouse environment as well as the key physiological indicators (leaf area, chlorophyll) information in the main crop growing period. According to the monitoring



data, analysis of environment and the corresponding relation of crop yield and quality to build facilities crop environment precise regulation model (shown in Figure 2).

Figure 2. Establish Diagram of Environment Regulation Model

The main purpose of the paper as follows: study the effect of illumination on photosynthesis of one certain crop, find out the influence regulation of illumination on crop photosynthesis, thus draw the required ratio of red and blue light in different periods of the whole growth cycle; Study the effect of temperature on photosynthesis of one certain crop, find out the influence regulation of temperature on crop photosynthesis, thus get the optimum temperature range in different periods of the whole growth cycle; Study the effect of humidity on photosynthesis of one certain crop, find out the influence regulation of humidity on crop photosynthesis, thus get the optimum humidity range in different periods of the whole growth cycle; Study the effect of CO_2 concentration on photosynthesis of one certain crop, find out the influence regulation of CO_2 concentration on crop photosynthesis, thus get the optimum CO_2 concentration range in different periods of the whole growth cycle; Study the effect of nutrient concentration on photosynthesis of one certain crop, find out the influence regulation of nutrient concentration on crop photosynthesis, thus get the optimum nutrient concentration range in different periods of the whole growth cycle. On the basis of getting the optimal range of individual factor impact on crop photosynthesis, some elements will be removed from several different factors in the interval ratio respectively, through the method of experiments and data fusion, the crop growth status in different periods will be observed, the overlap interval for each of the different stages of crop growth needed will be identified.

3. Research and Design of LED Light

3.1. Establishment and Simulation of the LED Light Source Model

Based on the crop growth mechanism, the research of requirement characteristics, regular, light control benchmarks, etc. in crop growth and development, red and blue LED were selected as the light source for crop growth. According to the wavelength, the light intensity, the light intensity distribution and other characteristics of LED light source, simulation software Tracepro was used to build LED optical model and to get LED spectral energy distribution and control parameters, then design a controllable LED light source which can regulate and control light quality, light intensity, light photoperiod, and work form (*e.g.*, flash frequency, continuous and discontinuous), LED illumination simulation model was shown in Figure 3.

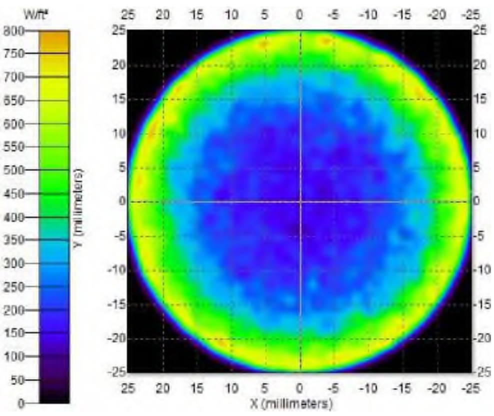


Figure 3. LED Illumination Simulation Model

3.2. Design of LED Crop Grow Light Source

Considering the impact of LED crop growth light on crop photosynthesis, based on the actual needed amount of light in different stages and different environments of crop growth, permutations of red and blue LED were used to design the light, Red LED lights have the narrowband red of a center wavelength of 660nm, Blue LED lights have the narrowband blue of center wavelength of 450nm, so as to achieve sub-wavelength quantitative, supply the light timely as required.

The crop growth LED light source adopted the new generation of ARM microprocessor STM32 as the core processor, using PWM (pulse width modulation) signal to achieve the intensity control of red, blue LED light, produced the light which crop photosynthesis needed. The System adopted modular design method, including control module, LED module, test module, early warning module, user interaction module and power module, etc., the system design principle diagram as shown in Figure
4.

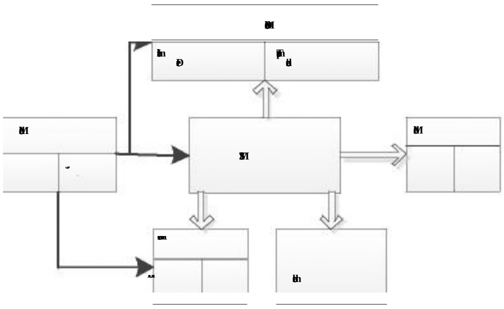


Figure 4. LED Crop Growth Light Source System Design Principle

Power
220V
Control Module
User
interaction
Warning
tor

Among them, the power module transformed the 220V voltage to 5V via a standard buck converter circuit. Detection module detected the real-time temperature and light intensity, and transferred these signals to the microcomputer, so as to realize the data acquisition of temperature, light information. Pre-warning module detected current illumination and temperature in real time, if the value was more than threshold, the buzzer alarmed and signal light was lit at the same time. Light module used two lines of constant current drive circuit and PWM control technology, respectively controlled the red, blue LED array brightness. Users could manually adjust the PWM duty ratio by the interaction module to change the LED brightness to achieve accurate light.

3.3. Achievement of LED crop growth light source

Crops grow light was designed in the paper, by adjusting the brightness of red and blue, to reduce the high power LED junction temperature, thereby reduced the effect of temperature on LED red and blue wavelengths, the detection module automatically was adjusted by the current intensity, greatly reduced the crop growth cycle. The LED crop growth light controlled the red and blue light intensity through the serial port, in order to meet the needs of different crops illumination. LED crop growth light's actual effect was shown in Figure 5.

Figure 5. LED Crop Growth Light's Physical Effect

4. System Hardware Design of Crop Growth Cabinet

The simulation system of crop growth environment was required to distribute and control environmental factors inside the crop growth cabinet, including the temperature, humidity, illumination, carbon dioxide, etc. In order to realize effective control, firstly we should collect environmental information; secondly we needed to realize the real time control.

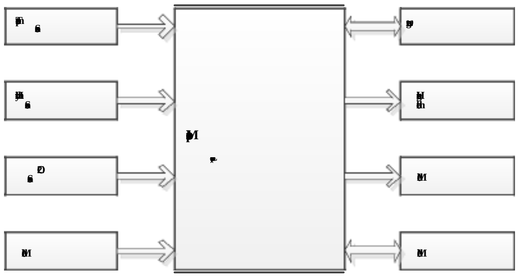


Figure 6. Overall Design Diagram of Hardware System

Hardware system overall design diagram was shown in Figure 6, Master control module used the low power consumption embedded system as the control core, configuring corresponding clock module, perception module, execution module and power module, *etc.*

In the paper, ARM architecture embedded microcontroller processor (S3C2440) and the embedded operating system (Linux2.6 [?]) were used to build the software and hardware platform. The working process of the system was shown as follows: firstly, the environmental indicators was set through the human-computer interaction interface, and then send them to master control module; secondly, the master control module collects information of temperature, humidity, CO2 [?] concentration and other environmental indicators through the perception module, compared to the set of environmental indicators, if the index did not conform to the requirements, master control module would issue the instructions to make perform module corresponding equipment act, until the sensing module tested once until meet the requirement of setting, finally we simulated the suitable ecological environment for crop growth.

4.1. Selection of Embedded Micro Controller Processor

Microprocessors based on ARM architecture are most widely used currently and divided into the ARM7, ARM9, ARM9E, ARM10, ARM11 and Cortex series. The ARM9 structure of Samsung S3C2440 production which runs faster in the industrial field was adopted in the paper. It was provided by Samsung Company to solve general type applications of small micro-controller which had low price, low power consumption.

S3C2440 used the 0.13 um CMOS standard components and memory compiler. It was ARM920T kernel, supporting 16/32 bit RISC and advanced microcontroller bus architecture (AMBA), was a high cost performance, low power consumption microprocessor chip, and provided a set of complete system peripherals interface. The structure of S3C2440 was shown in Figure 7.

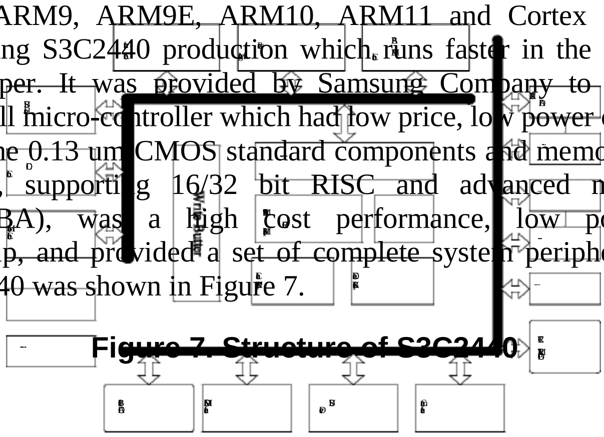


Figure 7. Structure of S3C2440

4.2. Sensor Module

In the process of crop growth, environmental parameters were not consistent in different measurement position, so a plurality of sensors should be placed at various locations to form a sensor network, comprehensively monitored crop growth environment, made crops get the best conditions in real time. Sensors placement positions were shown in Table 2.

Table 2. Collecting Information and Sensor Positions

Collecting information	Sensor positions
Nutrient solution temperature	crop root system
Leaf temperature and humidity (below)	Leaf layer(below)
Leaf temperature and humidity (middle)	Leaf layer(middle)
Leaf layer CO_2 concentration	
Leaf temperature and humidity (above)	Leaf layer(above)
Canopy temperature	Top of crops
Illumination	
Atmospheric CO_2 concentration	
Atmospheric temperature and humidity	

4.3. Actuator

Crop growth and development need a wider environmental range, as long as the environment parameters are controlled in a certain range that can meet the needs of the crop. Therefore, contact control was used to control temperature, relative humidity and CO_2 concentration in crop growth cabinet. When the environment parameter of sensor detection was higher than the upper limit of set value, the control actuator would turn on (off); when the environmental parameter detection reached the lower limit of the set value, the control actuator would turn off (on).

Execution module was mainly comprised of LED light source, environment heater, environmental cooler, fan, water pump, Nutrient solution heater or cooler, humidifier, carbon dioxide generator etc. which were used to adjust the parameters, was the executor of an intelligent control system, was used to control environment in the cabinet to achieve crop growth requirements.

Environment heater, environmental cooler, fan, water pump, Nutrient solution heater or cooler, humidifiers and other enforcement agencies were controlled by the relays, and the relays were controlled by STM32 microprocessor.

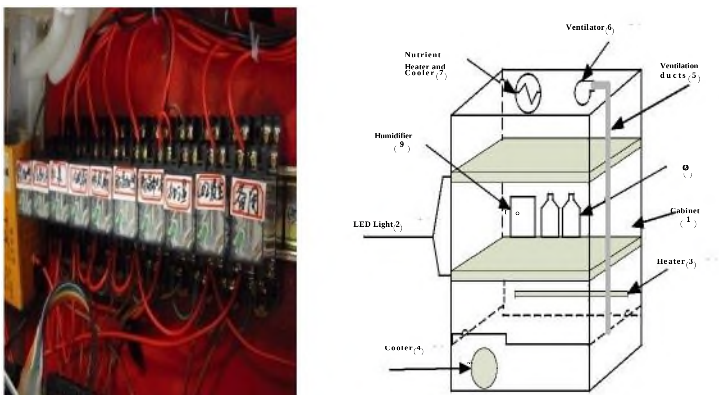


Figure 8. Crop Growth Cabinet Relay and Actuator Distribution

The sensor module and actuator module were the key parts of hardware design of the entire crop growth environment simulation system for crop growth, and hold the very great proportion of the whole system hardware. The setting of actuators in the crop growth cabinet was the key to realize the artificial simulation of the natural environment; crops would get the best living conditions in the entire growth cycle by operating the actuators component. Actuators distribution influenced whether crops would get optimum growing conditions, actuators distribution were shown in Figure 8, the left was all relays distribution in crop growth cabinet, the part was the distribution of the implementing agencies, under two LED light source board, two row crop frame were placed to use for placing the nutrient solution for the growth of crops.

5. Design of System Software

"Host machine / target board" (Windows + virtual machine + S3C2440A) cross development mode was generally adopted in the embedded systems as shown in **Fig.9**, which used the software and hardware resources, and integrated development environment and debugging tools of the host machine (Windows) to develop the software on the target board. The target board was the practical running environment of the embedded applications, whose hardware resources were limited, system software cannot run until having been reduced and configured. Applications were compiled to produce executable files under the host machine's integrated development environment (VMware), and downloaded to the target board through the serial/USB/crossover cables, etc. ,used the cross debugger to monitor, analysis, debugged the running process online real-time, to achieve the debugging of the embedded system software, eventually applications were cured to the target board.

User application program (AP) was the core part of the crop growth environment simulation system, the design flow chart was shown in Figure 10.

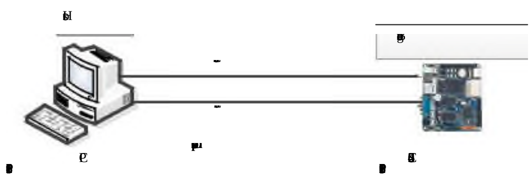


Figure 9. "Host Machine / Target Board" Cross Development Mode

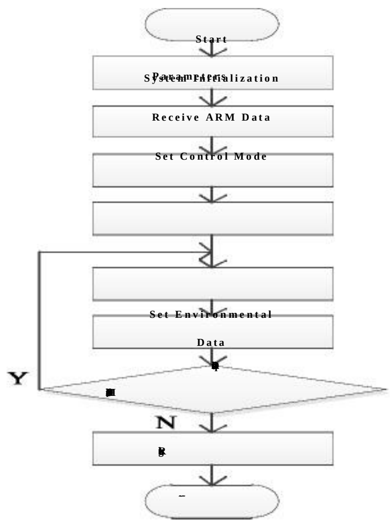


Figure 10. User Application Program (AP) Design Flow Chart

6. Design of System Interface

The man-machine interface, as the media of operator and the underlying hardware and software system, was needed to meet the software design principles of friendliness and usability, such as beautiful appearance, and easy to operate and understand. Crop growth environment simulation system mainly contained sensor module, data storage module, data processing module, actuator module, data query module, etc. GUI outlined the system interface of human-computer interaction, was the result display of the first three functions. GUI's development was based on embedded hardware development, and this paper used QT as the development tool to design the system interface.

The design of man-machine interface of this paper contained: boot interface, primary interface and secondary interface. The primary interface included some main interfaces of parameter display, automatic mode, the manual mode, the default mode, data acquisition, system description and so on. The QT applications written in PC could run in the embedded target board after cross compile. The setting of all working parameters and the normal operation of all functions of the instruments in crop growth environment simulation system were implemented by GUI. Here was the specific GUI interface hierarchical graph shown in Figure 11.

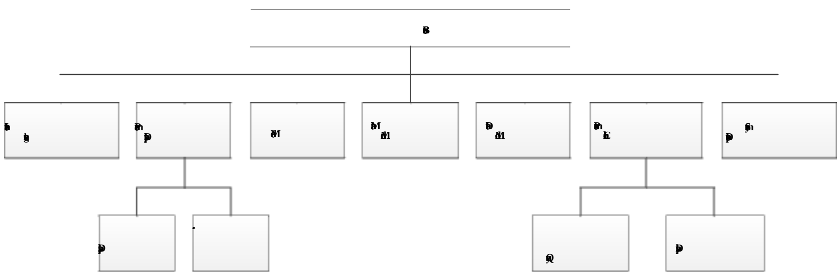


Figure 11. GUI Interface Hierarchical Graph

7. System Integration Test and Experimental Study

7.1. System Integration Test

In the crop growth environment simulation system, four kinds of power of 1.8V, 3.3V, 5V, 220V were involved ... Multimeter to measure, observed whether the output of the power module was normal.

The design of crop growth cabinet was an achievement of theory research of crop growth environment simulation system, the physical appearance of crop growth cabinet was shown in Figure 13. In ensuring the power module output under normal circumstances, checked operation of each actuator, test nutrient solution pH to ensure the pH value of nutrient solution. Leafy vegetable crops -- rape was used to test integrally in the system, fully test the quality of crop growth cabinet hardware and software design.

For the interface operating system, if RE and DE functions were enabled, after the communication succeed, it would receive data in order selectively.

Figure 13. Crop Growth Cabinet

7.2. Experiment and Study

The leaf vegetable rapes were used to study, a complete process of crop cultivation mainly included four stages of seeding, transplanting, hydroponic growth and maturity picking. Crop growth in different stages needed to meet the certain environmental factors.

Table 3. Environmental Parameters in Process of Crop Growth

Parameters / Stages	Light (type)	Temperature (˚C)	Humidity (%RH)	CO_2 (ppm)	Nutrient solution temperature (˚C)	Remark
Sowing	None	18-25	50	400	无	Sowing 8 days
Budding	None	18-25	50	400	None	Budding 7 days
Transplant Hydroponics	LED	25-30	75	950	Day:20 Night:24	Transplant after15 days of sowing, 45 days maturity

Sowing and seedling:

We sprinkled vegetable seed in the flower pot, maintaining an appropriate growth environment only including appropriate temperature and humidity, but light and carbon dioxide concentration were not required.

Transplanting cultivation:

Seeds in the flower pot would grow a small bud after 13-16 days, after having 3-4 leaf, could be transplanted. Seedling root should be paid attention to protect in transplanting process, minimizing the damage, the steps were as follows:

(1) Carefully removed the seedlings from the flower pot, washed off soil or other substrates with clear water;

(2) Cut off the old roots, dead roots and excess lateral roots;

(3) Pack the roots with sponges, put them in a hydroponic cultivation panel hole, poured the nutrient solution prepared well into the crop cultivation device (sink), nutrient solution preparation proportion according to the instructions, the general proportion was1:100 and 1:70.

Hydroponic growth:

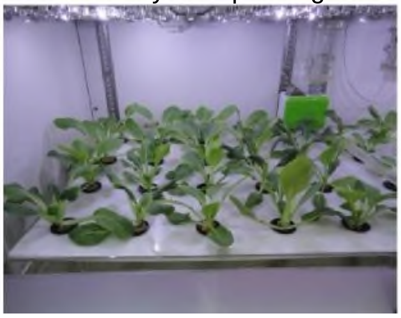
The stage of hydroponic growth was one of the most important stage during the whole process of crop growth and cultivation, this stage was mainly finished by crop growth cabinet control system, provided a suitable environment for crop growth.

Maturity picking:

Rape would be maturity basically after 45 days from seedling, and could be harvested. The growth of Rape in the whole life cycle, in different time period was shown in Figure 14.

The early transplanting

Early growth of 15 days



Medium-term growth of 31 days

Maturity period of 45 days

Figure 14. Rape Growth

The crop growth cabinet was switched on time from 8 AM to 10 PM every day according to the schedule of crops. In the process of growing, rapes' height, leaf length and width were measured daily, using vernier caliper to measure the diameter of rape and recorded. From December 28, 2013 to February 11, 2014, the whole growth period of rape was 45 days, the measurement of rape growth evaluation parameter were shown in Table 4.

Table 4. Measurement of Rape Growth Evaluation Parameters

Culture Environ ment	LED Hydropo nics	Crop Species	Rape	Loca lion	1, 2 Layer	Number	1001 1002	Light Specie s	LED	Light height from hydroponic panel	200mm

Date	Crop Height (cm)	Diamete r(cm)	Leaf number (piece)	Leaf length (cm)	Leaf width(c m)	Number	Nutrient solution Instructions	R/B	Remark
2013.12.28	0	0	0	0	0	6	Soil culture		Sowing
2014.01.03	0	0	0	0	0	6	Soil culture		Budding
2014.01.06	0	0	2	0	0	6	Soil culture		
2014.01.12	3.4	3.9	3	2.6	1.5	6	Soil culture		
2014.01.13	4.0	4.2	4	3.0	1.7	6	Hydroponics	7:1	Transplant
2014.01.14	4.1	4.5	4	3.1	1.8	6	Hydroponics	7:1	Grow
2014.01.15	4.2	4.9	4	3.4	1.92	6	Hydroponics	7:1	
2014.01.16	4.7	5.2	5	3.6	2.0	6	Hydroponics	7:1	
2014.01.17	4..9	5.6	5	3.7	2.1	6	Hydroponics	7:1	
2014.01.18	5.1	6.0	6	3.9	2.2	6	Hydroponics	7:1	
2014.01.19	5.2	6.3	6	4.0	2.3	6	Hydroponics	7:1	
2014.01.20	5.2	6.8	6	4.3	2.35	6	Hydroponics	7:1	
2014.01.21	5.5	7.1	7	4.5	2.4	6	Hydroponics	7:1	
2014.01.22	5.8	7.4	7	4.7	2.5	6	Hydroponics	7:1	
2014.01.23	6.0	8.0	8	4.8	2.6	6	Hydroponics	5:1	

2014.01.24	6.3	8.1	8	4.8	2.7	6	Hydroponics	5:1	
2014.01.25	6.4	8.1	8	4.9	2.8	6	Hydroponics	5:1	
2014.01.26	6.6	8.3	9	5.1	3.0	6	Hydroponics	5:1	
2014.01.27	6.7	8.4	9	5.2	3.1	6	Hydroponics	5:1	
2014.01.28	6.8	8.4	10	5.3	3.2	6	Hydroponics	7:1	
2014.01.29	6.9	8.5	10	5.4	3.2	6	Hydroponics	7:1	
2014.01.30	7.0	8.5	10	5.5	3.3	6	Hydroponics	7:1	
2014.01.31	7.2	8.6	11	5.6	3.3	6	Hydroponics	7:1	
2014.02.01	7.4	8.6	11	5.7	3.4	6	Hydroponics	7:1	
2014.02.02	7.6	8.7	12	5.8	3.4	6	Hydroponics	7:1	
2014.02.03	7.9	8.8	12	5.9	3.5	6	Hydroponics	7:1	
2014.02.04	8.2	8.8	12	6.0	3.6	6	Hydroponics	7:1	
2014.02.05	8.5	8.8	12	6.1	3.6	6	Hydroponics	7:1	
2014.02.06	8.8	8.8	12	6.2	3.6	6	Hydroponics	7:1	
2014.02.07	9.1	8.9	12	6.3	3.6	6	Hydroponics	7:1	
2014.02.08	9.5	8.9	12	6.4	3.6	6	Hydroponics	7:1	
2014.02.09	10	8.9	12	6.5	3.6	6	Hydroponics	7:1	
2014.02.10	10.5	8.9	12	6.6	3.6	6	Hydroponics	7:1	
2014.02.11	10.7	8.9	12	6.7	3.6	6	Hydroponics	7:1	Maturity

7.3. Results and Discussion

ARM9 embedded processor was used as the core hardware of the system, and Linux embedded real-time operating system was used as the software platform. The way of contacts control was used to regulate the environmental parameters. ARM9 chip used as system development had the advantages of performance stable, rich peripheral resources, lower power consumption and so on. Linux embedded real-time operating system had the advantages of multitasking and open source code, improved the system's ability to handle concurrent tasks and meet the increasingly complex control requirements of crop growth environment simulation system, was the development direction of greenhouse control system in the future. In the design of human-computer interaction, QT was used to complete crop growth cabinet system interface design, data preprocessing module, measurement module, display module, query module and so on. Powerful advantages of QT made the GUI system based on QT become the major solutions of embedded visualization software systems development.

The paper used the LED light source of adjustable parameter as crop growth light source, with red, blue LED combination collocation design, LED red light could inhibit photosynthetic product output from leaf to increase leaf starch accumulation; LED blue light regulated the physiological process of chlorophyll formation, chloroplast development, stomata opening, rhythm of photosynthetic and so on, meet the needs of crop growth photosynthesis for light conditions.

Hydroponics cultivation mode was used in crops growth. We deployed nutrient solution independently depending on the different nutrients needs of crops. We used vernier caliper to measure the diameter of rapes and used a meter stick to measure rape height and leaf size daily in the growth cycle. The data were recorded every day, and got the rapes growing evaluation parameters. After picking rapes, we measured the fresh weight with electronic scales. From Table 4, we could find that rapes grew very well, achieved the sell requirements of the market. It not only proved that the design of the crop growth cabinet was able to provide a suitable environment for crop growth, achieved the design goal; but also proved the theory of artificial simulation crop growth environment was realized.

The experimental results showed that rapes grew very well and were superior to the mature rapes which grew in the natural environment, whose growth period was short, quality was good, yield was high. But the design of the crop growth cabinet was not perfect, there were some defects. Firstly, crop growth cabinet began to work from 8 am to

10 PM every day, according to the schedule of crops in nature, 12 hours of power supply, energy consumption was great. Secondly embedded application software was just finish the GUI design, we still need to design and optimize for data acquisition, transmission and processing, to obtain more accurate data for the establishment of crop growth model. The man-machine interface was also needed to be further optimized, to make the interaction of man-machine interface more convenient, improved the stability of the system. Thirdly, some part of the crop growth cabinet was artificial, intellectualized degree was not high, we still needed to further study in intelligent algorithm, data fusion, crop modeling and so on.

8. Conclusion

In this paper, an environment simulation system for crop growth (i.e., Intelligent Crop Growth Cabinet) was designed. The system used an LED light source of adjustable parameters, combined with embedded technology, sensor technology and other technology to achieve environment control for crop growth of temperature and humidity, light intensity, carbon dioxide concentration, *etc*. Experiments showed that the intelligent crop growth cabinet had the advantage *e.g.*, rational structure, reliable performance, low-carbon, intelligence and security.

The system used the LED light source to meet with adjustable parameters as the needed of photosynthesis for crop growth, which was designed with the combination of red and blue LED, had the advantages of environmental protection, energy saving etc. The system used ARM processor as the main control module, and configured a variety of sensors to real-time detects environment parameters of growth cabinet. According to the crop growth model required parameters, the system could regulate environment independently, and ensure the requirement of different stages in the process of crop growth and make crop grow well. The growth cabinet used insulated box structure, not only had the effect of thermal insulation, and easy to move, and could play a role to achieve low-carbon, intelligent, efficient, safe, clean, healthy and other effects.

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